

PITFALLS IN THE IDENTIFICATION OF THE 21 MICRON FEATURE

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ABSTRACT

The origin of the so-called “21 μm ” feature that is especially prominent in the spectra of some carbon-rich protoplanetary nebulae is the matter of a lively debate. A large number of potential band carriers have been presented and discarded within the past decade. We present some of the problems related to the hitherto proposed feature identifications.

Key words: circumstellar matter; infrared stars; laboratory methods.

1. THE 21 MICRON FEATURE

The “21 μm ” emission feature is prominent in the spectra of some carbon-rich protoplanetary nebulae (PPNs) and two extreme carbon stars. The broad feature is positioned at 20.1 μm and has a full width half maximum slightly larger than 2 μm . Observations indicate that a characteristic of the feature is that it only occurs in a short transitional phase of stellar evolution, i.e. in a very limited range of physical and chemical conditions. The stellar objects are all characterized by having C/O-ratios close to or greater than unity and a cool dusty environment with dust temperatures below 250 K. It appears that the 11.3 μm SiC feature, the 12+ μm plateau emission, and the “21 μm ” emission originate (approximately) in the same region, which indicates that similar physical and chemical conditions are required for the formation and/or survival of the respective carriers of the features. The feature was first discovered with IRAS - the Infrared Astronomical Satellite (Kwok et al., 1989) - and later resolved to actually be at 20.1 μm with ISO - the Infrared Space Observatory (Hrivnak et al., 2000).

2. THE POSSIBLE CARRIERS

A large number of potential band carriers have been presented and discarded within the past decade. The

current most promising carriers of the “21 μm ” feature are oxidized SiC, FeO, SiS₂, TiC clusters and carbonaceous macromolecules. From a spectroscopic point of view the oxides appear as the most likely band carriers, however, it is difficult to conceive a scenario accounting for their formation in a carbon-rich environment. On the other hand, dust species which are usually predicted to form in carbon-rich environments, like carbon, carbides and sulfides do not match the observed “21 μm ” band profile, or their maximum abundance is too small for emitting the energy contained in the “21 μm ” feature. Table 1 provides an overview of the positions of the absorption efficiency maxima and of the corresponding bandwidths.

Silicon disulfide: Goebel (1993), on the basis of IRAS spectra, assigned the “21 μm ” feature to silicon disulfide (SiS₂), based on the intense vibrational band in the 20 μm spectral range. However, SiS₂ has *two* infrared spectral bands, of which the second, located, at 16.8 μm for small spherical particles has no counter part in astronomical spectra.

Carbonaceous macromolecules: Papoular (2000) has calculated synthetic spectra of carbonaceous macromolecules containing OH, oxygen, sulfur, nitrogen, or a combination of them and found that it is possible to reproduce not only the “21 μm ” feature, but also the 3.3, 11.3, 12+, 26 and 30 μm bands by emission by such molecules. According to this scenario, the “21 μm ” feature would arise from out-of-plane vibrations of oxygen or nitrogen atoms in five-membered carbon rings. Papoular’s approach seems promising because it aims at an identification of *all* the major features detected in the sources of the “21 μm ” band on basis of *one* unified dust model. But at the time being, substantial problems remain, such as the unsatisfactory reproduction of the observed 26–35 μm band profile.

Titanium carbide: von Helden et al. (2000) suggested titanium carbide clusters made of 27–125 atoms, but Hony et al. (2003) argue that TiC, like any other dust, can only emit as much in the infrared as it absorbs in the UV and visual range, and for this energy balance to be fulfilled larger amounts of TiC

than expected have to form. This point was further strengthened by Li (2003) and Chigai et al. (2003) making the TiC scenario rather unlikely.

SiC with impurities or coatings: Speck & Hofmeister (2004) suggested silicon carbide with impurities as carrier of both the 11.3 and “21 μm ” spectral features. One of their arguments in favor of this hypothesis is the spatial co-location of both emission bands in some of the objects exhibiting them. However, N-doped SiC will not work since it also displays stronger additional bands at 15 and 17 μm (Suttrop et al., 1992), which are not seen in the sources of the astronomical “21 μm ” feature. For C-doped SiC there is presently too little information on analytically well-characterized samples. Promising candidates are oxidized SiC nano-particles since cold core-mantle particles composed of SiC and amorphous SiO_2 *do* produce a strong 20 μm feature with good agreement between the observed and calculated band positions and the weakness of the observed 11 μm feature 8 μm and 11 μm features can be explained by dust temperatures significantly lower than 160 K, on average, see (Posch et al., 2004). An SiO_2 coating presents the difficulty of explaining how oxides can form or at least survive in carbon-rich environments.

Cold FeO: While none of the “higher” iron oxides like Fe_2O_3 or Fe_3O_4 can survive in a reducing environment, iron monoxide (FeO, also called wustite), by contrast may survive in a carbon-rich circumstellar shell. Its formation in PPN envelopes would require the oxidation of Fe to FeO at low temperatures, which is indeed a fast process up to a depth of 6-8 atomic layers at the surface of iron grains. Thus, it seems that metal-poor PPNs such as HD 56126 provide good conditions for FeO formation (Posch et al., 2004), since this process requires the presence of small metallic iron grains. The absence of any feature attributable to FeO in the vast majority of the planetary nebulae (PNs), on the other hand, could be accounted for by the fact that FeO is reduced to Fe under UV irradiation (Duley, 1980). Thus, FeO can persist in only a narrow range of equilibrium between oxidation (to higher iron oxides) and reduction (to metallic iron), which indeed could meet the constraints for the carrier of this feature. O-baring molecules in a carbon-rich PPN have been observed with ISO by (Herpin & Cernicharo, 2000).

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Table 1. The most promising carriers of the “21 μm ” feature discussed within the past decade.

Candidate Carrier	Particle Shape	$\lambda(\text{C}_{\text{abs,max}})$ [μm]	FWHM [μm]
$\text{SiC}+\text{SiO}_2$ ^(a)	sph.	8.0,12.5,19.7–19.8	1.8
FeO ^(b)	sph.	19.9	2.3
	CDE-Osk	20.7	6.5
SiS_2	sph.	16.8,19.8	1.6
	CDE-Osk	16.8, 20.2	1.8
TiC clusters	sph.	20.0	2.0
	CDE-Osk	20.0	2.2
TiC grains	sph.	19.2	- ^c

Note: The observed position and FWHM of the “21 μm ” band are 20.1 μm and 2.3 μm , respectively. “CDE-Osk” designates a continuous distribution of ellipsoids according to Ossenkopf et al. (1992) and “sph” stands for spherical particles. The $\lambda(\text{C}_{\text{abs,max}})$ [μm] do *not* directly represent feature positions, since these result from the product $\text{C}_{\text{abs}} \times \text{B}_\nu(\text{T}_d)$; for dust temperatures close to 150 K, this leads to a shift toward the “red” of 0.1–0.2 μm .

^aCore-mantle-particles with SiC core volume fractions between 0.4 and 0.6.

^bAt an average temperature of ≈ 140 K.

^cBroad bump, FWHM not defined.

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